Claims

1. A method for calibrating a surveying instrument comprising a base element and a camera with an image sensor, the camera being rotatable about a vertical axis fixed with respect to said base element and being rotatable about a tilting axis, the tilting axis being rotated about the vertical axis with rotation of the camera about the vertical axis,
wherein data associated with calibration points and images of the calibration points on the image sensor captured in different faces are used, the data for each of said calibration points comprising distance data representing a distance between each said calibration point and the surveying instrument and the data for each of the images of each said calibration point comprising image position data representing the position of the image of each said calibration point on said image sensor and orientation data representing a horizontal angle of rotation of the tilting axis about the vertical axis and a vertical angle of tilting of the camera about the tilting axis, and
wherein on the basis of the distance data for each of the calibration points and the image position and orientation data for each of the images of the calibration points the surveying instrument is calibrated simultaneously taking into account at least one optical property of the camera and at least one of the relative orientation of the vertical axis and the tilting axis and the orientation of the camera relative to one of the base element, the vertical axis and the tilting axis.

2. A method for calibrating a surveying instrument comprising a base element and a camera with an image sensor, the camera being rotatable about a vertical axis fixed with respect to said base element and being rotatable about a tilting axis, the tilting axis being rotated about the vertical axis with rotation of the camera about the vertical axis,
wherein images of calibration points are generated at different positions on the image sensor and in two faces,
wherein for each of said calibration points the distance data representing a distance between the respective calibration point and the surveying instrument and for each image of said

calibration points position data representing the position of the image of the calibration point on the image sensor, orientation data representing a horizontal angle of rotation of the tilting axis about the vertical axis and a vertical angle of tilting of the camera of the tilting axis are determined, and

wherein on the basis of the distance data for each of the calibration points and the position and orientation data for each of the images of the calibration points the surveying instrument is calibrated simultaneously taking into account at least one optical property of the camera and at least one of the relative orientation of the vertical axis and the tilting axis and the orientation of the camera relative to one of the base element, the vertical axis and the tilting axis.

3. The method according to claim 1 or 2, wherein a model is used for calculating the positions of images of calibration points on the image sensor, the model comprising adjustable model parameters and using distance data and orientation data associated with each of the images of the calibration points, and for calibration the model is fitted to the position data by estimating at least directions of the calibration points and the model parameters using the distance data, the position data and the orientation data.

4. The method according to claim 3, wherein for estimation of the directions of the calibration points and of the model parameters a maximum likelihood estimate is used.

5. The method according to claim 3 or claim 4, wherein at least one of the model parameters depends on the distance of the calibration point from the surveying instrument or on a focusing state of the camera when capturing an image of the calibration point.

6. The method according to any of claims 3 to 5, wherein the model comprises a transformation for transforming coordinates in an instrument coordinate system fixed to the base element to a camera coordinate system fixed to the camera and a camera model for mapping positions of calibration points to positions on the image sensor in the camera coordinate system, the transformation having adjustable transformation parameters and the camera model having adjustable camera parameters, and for calibration the coordinates of the calibration points in the instrument coordinate system and the transformation parameters and camera parameters are estimated, so that positions of the images of the calibration points as calculated by the model are fitted to the measured positions of images of the calibration points.

7. The method according to any of the preceding claims, wherein the calibration is performed also taking into account at least one of a vertical index error and a collimation error.

8. The method according to any of the preceding claims, wherein the calibration includes estimating the orientation of the camera relative to one of the tilting axis and an instrument coordinate system fixed to the base element.

9. The method according to any of claims 3 to 6, wherein the camera model comprises a projection center in which according to the camera model all rays from object points imaged onto the image sensor intersect, and wherein at least one model parameter relates to the location of the projection center.

10. The method according to any of the preceding claims, wherein the distance data associated with at least two calibration points differ.

11. The method according to any of the preceding claims, wherein images captured by the image sensor are obtained, the captured images comprising images of at least one of the calibration points, and wherein the position of said images of said at least one of the calibration points on the image sensor is determined by searching for the images of the calibration point in the images.

12. The method according to claim 2 or to any of claims 3 to 11 and claim 2, wherein the distance of at least one of the calibration points to the surveying instrument is determined using opto-electronic distance metering.

13. The method according to any of claims 2 or 12 or to any of claims 3 to 11 and claim 2, wherein at least one object point is imaged to a virtual calibration point which is imaged onto the image sensor.

14. The method according to claim 13, wherein the virtual calibration points are generated by means of a collimator and a mark that can be shifted between a collimator objective and a focal point of the collimator objective.

15. The method according to claim 2 or to any of claims 3 to 14 and claim 2, wherein for at least one of the calibration points the positions of images of the image sensor are predetermined, wherein the camera is directed to the calibration point by at least one of rotating about the vertical axis and tilting about the tilting axis until the calibration point is imaged to the predetermined position of the image sensor, and wherein the resulting orientation data are read.

16. The method according to claim 14, wherein for at least one of the calibration points images of the calibration point are generated in a regular arrangement on the image sensor.

17. The method according to claim 15, wherein for at least one of the calibration points an arrangement of cells covering a predetermined area of the image sensor is generated and random positions within the cells are used as positions of images of the calibration point.

18. The method according to claim 2 or to any of claims 3 to 14 and claim 2, wherein for at least one of the calibration points the camera is directed into predetermined orientations, the orientations being defined by predetermined combinations of horizontal and vertical angles or horizontal and vertical angle increments, and wherein in each orientation image position data for a respective image of the calibration point are obtained.

19. The method according to claim 18, wherein the image position data and the corresponding orientation data are obtained for both faces.

20. A data processing system comprising a processor, a memory, in which there is stored a computer program for performing the method according to claim 1 or according to any of claims 3 to 11 and claim 1, when the program is executed by the processor, and further comprising an interface for reading data associated with calibration points and images of the calibration points used in the method.

21. The data processing system according to claim 20, further comprising an output interface for outputting commands to a drive of a collimator for moving a mark of the collimator between an objective of the collimator and the focal point of the collimator, wherein the computer program comprises instructions to move the mark to generate virtual calibration points at different distances.

22. The data processing system according to claim 20 or 21, further comprising an interface for issuing control commands to the surveying instrument, the surveying instrument comprising a base element and a camera with an image sensor, the camera being rotatable about a vertical axis fixed with respect to said base element of the surveying instrument and being rotatable about a tilting axis, the titling axis being rotated about the vertical axis with rotation of the camera about the vertical axis and the surveying instrument comprising drives for rotating the camera about the vertical axis and tilting the camera about the tilting axis controllable by the control commands, the computer program further comprising program code to generate images of a calibration point and predetermined positions on the image sensor.

23. A computer program comprising program code for performing the method according to claim 1 or any of claims 3 to 11 and claim 1 when the computer program is run on a computer.

24. A computer program product comprising program code stored on a computer readable storage medium for performing the method according to claim 1 or any of claims 3 to 11 and claim 1, when said program product is run on a computer.

25. A computer program according to claim 23 or a computer program product according to claim 24, further comprising a program code to generate images of a calibration point and predetermined positions on the image sensor by issuing control commands to the surveying instrument.

26. A system for calibrating a surveying instrument, the surveying instrument comprising a base element and a camera with an image sensor, the camera being rotatable about a vertical axis fixed with respect to said base element and being rotatable about a tilting axis, the tilting axis being rotated about the vertical axis with rotation of the camera about the vertical axis, the system comprising a collimator, a mark that can be shifted between a collimator objective and a focal point of the collimator objective, and a drive for shifting the mark, and a data processing system according to claim 19 or to claim 19 and 20, the output interface being connected with the drive of the collimator to move the mark in response to control commands generated by the data processing system.

27. A surveying instrument comprising a base element and a camera with an image sensor, the camera being rotatable about a vertical axis fixed with respect to said base element and being rotatable about a tilting axis, the tilting axis being rotated about the vertical axis with rotation of the camera about the vertical axis, the survey instrument being calibrated using a method according to any of claims 1 to 19.

28. A surveying instrument having a camera with an image sensor, wherein imaging of an object point by the camera on the image sensor can be modeled by use of a camera model having a projection center, a display for displaying images based on images captured by the image sensor, and a control unit for controlling the display to display a mark indicating a sighting axis, the sighting axis being defined by the projection center and the intersection point or point of closest approach of the tilting axis and the vertical axis.

29. A surveying instrument comprising a base element and a camera with an image sensor, the camera being rotatable about a vertical axis fixed with respect to said base element and being rotatable about a tilting axis, the tilting axis being rotated about the vertical axis with rotation of the camera about the vertical axis, wherein imaging of an object point on the image sensor by the camera can be modeled by use of a camera model working a coordinate system

fixed to the camera and a transformation model for transforming coordinates between an instrument coordinate system and the camera coordinate system, the instrument further comprising a data processing unit, in which program code is stored for determining a direction of an object point captured by the camera using the camera and transformation models, wherein a direction from the origin of the instrument coordinate system to the object point is calculated using a direction obtained by means of the camera model and the transformation model and the distance of the object point from the origin of the instrument coordinate system.

30. A computer program for a surveying instrument, the surveying instrument comprising a data processing system, a base element and a camera with an image sensor, the camera being rotatable about a vertical axis fixed with respect to said base element and being rotatable about a tilting axis, the tilting axis being rotated about the vertical axis with rotation of the camera about the vertical axis, wherein imaging of an object point on the image sensor by the camera can be modeled by use of a camera model working in a coordinate system fixed to the camera and a transformation model for transforming coordinates between an instrument coordinate system and the camera coordinate system, the computer program comprising program code for determining a direction of an object point captured by the camera using the camera and transformation models, wherein a direction from the origin of the instrument coordinate system to the object point is calculated using a direction obtained by means of the camera model and the transformation model and the distance of the object point from the origin of the instrument coordinate system when the program is executed by the data processing system.